PARAMETER ANALYSIS OF COPPER-NICKEL-TUNGSTEN PREPARED VIA POWDER METALLURGY PROCESS FOR ELECTRICAL DISCHARGE MACHINING OF POLYCRYSTALLINE DIAMOND

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A thesis submitted in fulfilment of the
requirement for the award of the Degree of Master of
Mechanical Engineering

Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia

SEPTEMBER 2019

DEDICATION

SPECIAL GRATITUDE TO:

Special for my parent,

SABRI BIN OMAR & MASIHAH BINTI MD. ZAIN

"Thanks for your continuous morale and support"

"Your inspiration will always with me"

Especially for my kind supervisor that give encouragement and support

DR. MOHAMMAD ZULAFIF BIN RAHIM

"Thanks for the knowledge and advice given"

My lovely siblings,

"Thanks for your support and encouragement in everything"

Also, to all my friends that give full support,

Only Allah S.W.T can repay your kindly

Hope Allah S.W.T blesses our life

ACKNOWLEDGEMENT

Praise be to Allah, The Most Merciful, The Most Compassionate, for granting me the chance and strength to complete this thesis for Master Degree, which undoubtedly bring me into heights of intellectual and emotional enrichment.

My highest gratitude goes to my supervisor, Dr Mohammad Zulafif bin Rahim who throughout completing this research not only provides me with guidance, advice but generously also shares with me his insights and understanding needed to complete this project. Thus, I wish to express my deepest gratitude and appreciation to him for his generosity, critics and intellectual support. I also want to thank Associate Professor Ts. Dr. Mohd Rasidi Bin Ibrahim who assign as my co-supervisor and the lecturers and staffs of FKMP for their cooperation during the completion of the master research that had given valuable information, suggestions and guidance in the compilation and preparation master report.

Besides that, I would like to thank to all technicians and Precision Machining Research Centre (PREMACH) members who were willingly lending their helping hand in laboratory and experiment work. I extend my thankfulness to all my fellow friends. My deepest appreciation goes to my beloved family who always showers me in each and every moment with love, motivation and prayers.

I would like to acknowledge the Ministry of Higher Education (MOHE) Malaysia under Fundamental Research Grant Scheme (FRGS) grant, Vot 1586 (Parameter Correlation and Mechanism in Catalytic Erosion of Polycrystalline Diamond) for financial support.

Lastly, thanks a lot to those who had giving a hand, directly or indirectly in helping me to finish my research and thesis successfully.

ABSTRACT

Polycrystalline Diamond (PCD) tools have an outstanding wear resistance. The electric conductivity of PCD caused by the conductive binding material (Cobalt) makes it possible to machine PCD tools with EDM. Electrode used in EDM of PCD must have better porosity, electrical and thermal conductivity. Therefore, this research presents the works in production of Cu-Ni-W electrode by powder metallurgy route. Production of powder metallurgy parts involve mixing of the powder with additives or lubricants, compacting the mixture and heating the green compacts in an Argon gas furnace so the particle bond to each other. Two levels of full factorial with six centre points and two replication technique was used to study the influence of main and interaction effects of the powder metallurgy parameter. There were four factors involved in this experiment. Factor A which is Type of Cu-Ni; Type A and Type B was defined as categorical factor. Factor B in which Composition of W; 5 Wt.%, 15 Wt. % and 25 Wt.%, was defined as numerical factor. Factor C which is the Compaction load; 7, 8 and 9 tonne and Factor D which is Sintering temperature; 635 ℃, 685 ℃ and 735 ℃ were also defined as numerical factor. Optical Microscope, Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray (EDX) was used to analysed the microstructure and surface morphology of Cu-Ni-W electrode. The best parameter combination to produced better porosity, electrical and thermal conductivity for both Type A and Type B was 5 Wt.% of W, compaction load at 9 tonne and sintering temperature at 735℃. The best response for Type A is 12.65% of porosity, 14.40 IACS% of electrical conductivity and 413.26 W/m.℃ of thermal conductivity. While that, the best response for Type B were 9.36% of porosity, 16.66 IACS% of electrical conductivity and 345.21W/m.℃ of thermal conductivity. From the calculation of Maxwell's Equation, Type A and Type B had the highest electrical conductivity of 58.48 IACS% and 77.35 IACS% respectively at W content of 5Wt.%. Type A and Type B also had the highest thermal conductivity of 369.86 W/m.℃ and 310.24 W/m.℃ respectively at W content of 5 Wt.%. Besides that, thermal conductivity also increased with the temperature increased until 450℃.

ABSTRAK

Alat *Polycrystalline Diamond* (PCD) mempunyai rintangan haus yang bagus. Pemesinan EDM terhadap PCD dapat dilakukan disebabkan oleh bahan pengikat di dalam PCD iaitu kobalt mempunyai kekonduksian elektrik. Elektrod yang digunakan dalam pemesinan EDM terhadap PCD harus mempunyai keliangan yang lebih baik, kekonduksian elektrik dan haba. Oleh sebab itu, penyelidikan ini membentangkan produksi elektrod Cu-Ni-W dengan menggunakan kaedah metalurgi serbuk. Proses metalurgi serbuk melibatkan pencampuran serbuk dengan aditif atau pelincir, memampatkan campuran dalam acuan yang sesuai dan sampel dilakukan *sintering* dalam gas Argon. Dua tahap faktorial penuh dengan enam titik pusat dan dua teknik replikasi digunakan untuk mengkaji pengaruh kesan utama dan interaksi parameter metalurgi serbuk. Terdapat empat faktor yang terlibat dalam eksperimen ini. Faktor A ialah Jenis Cu-Ni; Jenis A dan Jenis B didefinisikan sebagai faktor berkategori. Faktor B di mana komposisi W; 5 *Wt.%*, 15 *Wt.%* dan 25 *Wt.%*, ditakrifkan sebagai faktor berangka. Faktor C iaitu Beban Pemadatan; 7, 8 dan 9 tan dan Faktor D ialah suhu Pembakaran; 635 ℃, 685 ℃ dan 735 ℃ juga ditakrifkan sebagai faktor berangka. Mikroskop optik, Mikroskopi Pengimbasan Elektron (SEM) dan *Energy X-ray Dispersive* (EDX) digunakan untuk menganalisis struktur mikro dan permukaan morfologi Cu-Ni-W komposit. Gabungan parameter yang terbaik untuk menghasilkan keliangan yang lebih baik, kekonduksian elektrik dan haba untuk kedua-dua Jenis A dan Jenis B ialah dengan 5 *Wt.%* W, beban pemadatan pada 9 tan dan suhu sintering pada 735 ℃. Tindakbalas best untuk Jenis A adalah 12.65% keliangan, 14.40 IACS% daripada kekonduksian elektrik dan 413.26 W / m. ℃ kekonduksian haba. Sementara itu, tindak balas best untuk Jenis B adalah 9.36% keliangan, 16.66 IACS% daripada kekonduksian elektrik dan 345.21W / m. ℃ kekonduksian haba. Dari pengiraan dengan menggunakan persamaan *Maxwell*, Jenis A dan Jenis B didapati mempunyai kekonduksian elektrik yang tinggi iaitu 58.48 IACS% dan 77.35 IACS% setiap satu pada 5 *Wt.%* komposisi W. Pada 5 *Wt.%* komposisi W juga, kekonduksian haba maksimum bagi Jenis A adalah 369.86 W/m.℃ dan Jenis B adalah 310.24 W/m.℃. Selain itu, dengan kenaikan suhu sehingga 450 ℃, kekonduksian haba juga semakin meningkat.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATION

Cu	-	Copper
Cu-Ni	-	Copper-nickel
Cu-Ni-W	-	Copper-nickel-tungsten
EDM	-	Electrical Discharge Machining
PCD	-	Polycrystalline Diamond
Ni	-	Nickel
W	-	Tungsten
O	-	Oxygen
C	-	Carbon
W	-	Watts
˚C	-	Degree Celsius
M	-	Meter
K	-	Kelvin
μ	-	Micro
Λ	-	Thermal Conductivity
Σ	-	Electrical Conductivity
P	-	Density
G	-	gram
Cm^3	-	Centimetre cubic
Wt. %	-	Weight Percentage
Rpm	-	Revolution per minutes
SEM	-	Scanning Electron Microscopy
EDS	-	Energy Dispersive X-ray Spectroscopy
IACS%	-	International Annealed Copper Standard

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Diamond is among the hardest material in the world that is produced through sintering process of selected diamond particles at high temperature and high-pressure condition. Due to the outstanding wear resistance of Polycrystalline Diamond (PCD) manufactured by sintering selected diamond particles, cutting tools made of PCD have extensive tool life and outstanding performance in machining non-ferrous metals and non-metallic materials [1]. However, PCD tools are very difficult to fabricate and the high manufacturing costs of PCD tools seriously impede its application in the industry. Since 2010, extensive research has been initiated to increase PCD machining efficiency and tool quality [2, 3]. However, there is no substantial development has been achieved due to the lack of innovative approaches and new theories to solve the two fundamental problems in machining PCD; the ultra-hardness of diamond particles and the low electrical conductivity of PCD material. This leads to the high manufacturing cost caused by the long machining time that becomes a major drawback to the application of PCD tools: a brazed PCD tool is about 10 times expensive than a W carbide tool, and the price of a vined PCD tool is about 20 times higher than the carbide ones [4].

Electrical Discharge Machining (EDM) is a noncontact thermal erosion process in which the metal is removed by a series of recurring electrical discharges between the electrode and the electrically conductive work piece, in the presence of dielectric fluid. Figure 1.1 shows the illustration of the basic components of the EDM process. The electric conductivity of PCD caused by the conductive binding material (Cobalt) makes it possible to machine PCD tools with EDM. However, the low electrical conductivity of Polycrystalline Diamond makes the EDM process almost

three times slower than EDM of conductive metals. The crucial problem that causes low machining efficiency in EDM of PCD is the low electricity conductivity of PCD [5].

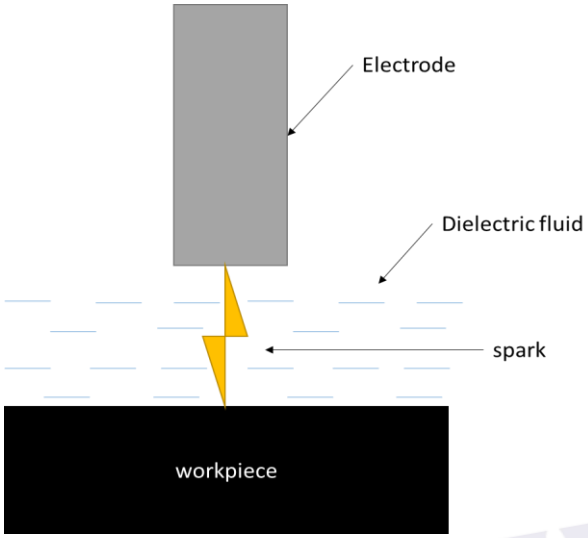

Figure 1.1: EDM illustration

Electrode used in Electrical Discharge Machining plays an important role to improve the efficiency of machining that is considered as a tool in EDM process. Electrode acts as a path for electrical current to be supplied to the sparking position. The acceleration of electrode towards the workpiece will generate heat and cause erosion. The performance of EDM process is largely dependent on electrode material and manufacturing process. The electrode that is able to provide the highest material removal rate (MRR) and the lowest tool wear is the most desired [6]. In this case, the electrode material properties such as electrical conductivity, thermal conductivity, and melting point should be considered in addition to the manufacturability and cost [7].

Copper (Cu) electrode is normally used for Electrical Discharge Machining of ordinary material due to its high electrical and thermal conductivity. The electrode is mentioned to offer fine surface finish of product without the requirement of secondary process of polishing [7]. To improve the wear resistant of the electrodes, Tungsten (W) that has high melting point is normally added [8]. Since slow erosion process in PCD EDM causes a significant electrode wear ratio, this improvised Cu electrode (named as Copper Tungsten, Cu-W) plays an important role in this application. Though

recently, it was mentioned that the Cu-Ni electrode provides better surface finish than Cu-W electrode in micro-EDM of PCD [9].

As short circuit pulse frequently appears during the PCD EDM process (PCD is touching the electrode), there is a high probability of graphitisation catalyst process taking place. When diamond particles come into contact with the graphitisation catalyst material (in this case Nickel (Ni)) at high temperature, carbon atoms in diamond will be diffused. Hence, it is possible for the graphitization of diamond particles to be accelerated (catalyst phenomenon). Thus, melting temperature of PCD surface reduces significantly due to the acceleration of graphitization (diamond to graphite conversion) that consequently increases the MRR.

In this research, the development of Copper-Nickel Tungsten (Cu-Ni-W) electrode properties is believed to provide better improvement in Electrical Discharge Machining of Polycrystalline Diamond. It is different from the manufacturing of Cu-W electrode where very small composition of Ni is usually added as activator during solid phase sintering in powder metallurgy route, in which higher content of Ni is purposely added [10]. The Ni not only acts as the activator during solid phase sintering, but also as the catalyst during Electrical Discharge Machining of Polycrystalline Diamond.

Manufacturing of EDM electrodes is usually done by using conventional alloying technique which is casting. However, this technique is found suitable only for less complex electrodes material composition [6]. In fact, significant differences in melting temperature of alloying materials give challenge to the casting process. In the case of Cu-Ni-W production, Cu with vaporisation temperature of 2595˚C is expected to vaporize first before tungsten begins to melt at temperature 3422℃ [11]. Hence, powder metallurgy is believed to provide better ability in combining several alloying materials. Due to this reason, powder metallurgy is selected as the manufacturing process to produce the Cu-Ni-W electrode in this research.

1.2 Problem Statement

Nowadays, there are a number of electrodes available in the market for Electrical Discharge Machine. These include Cu-Ni, Cu-W, Cu, brass, and graphite[12, 13, 14]. However, there is no electrode purposely developed for EDM of PCD. Market available Cu-Ni is able to provide better surface roughness of eroded PCD but believed as unable to deliver at least similar wear resistant as Cu-W electrode [9]. Moreover, until now, there is no Cu-Ni-W electrode available in the market, thus limits its exploration and application in PCD EDM [15, 16, 17]. The emergence of Cu-Ni-W electrode is expected to overcome the limitation. However, the information on the manufacturing process of this electrode is limited. In fact, the information on electrode development using powder compaction is only limited to a certain material only, such as Cu-W [18, 19]. Hence the information on thermal and electrical characteristic of the Copper-Nickel-Tungsten (Cu-Ni-W) electrode produced by the process is also limited [20, 21].

1.3 Objectives of Study

The aim of the project is to develop an electrode purposely designed for Electrical Discharge Machining of Polycrystalline Diamond.

The detailed objectives are:

i) To determine the significant parameter that influences the porosity, electrical and thermal conductivity of Cu-Ni-W by using Design of Experiment (DOE) Analysis.
ii) To investigate the effect of different powder metallurgy process parameter on porosity density, electrical and thermal conductivity of the Cu-Ni-W Composites.
iii) To analyse the surface morphology and microstructure of Cu-Ni-W composites prepared with different process parameter.

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